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A PRELIMINARY INVESTIGATION OF THE ZINC DUST PURIFICATION OF ZINCEX PROCESS ZINC CHLORIDE SOLUTION

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September 1990

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Project: 30.52.08
Zinc Processing

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MINERAL SCIENCES LABORATORIES
DIVISION REPORT MSL 90-79 (TR)

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39 pp

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by

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ABSTRACT

The first-stage solvent extraction strip liquor produced in the Zincex process is a nearly-neutral, impure zinc chloride solution. This solution was treated with zinc dust to control impurities such as Cu, Cd, Pb, As, Ni, Sn and Sb which are detrimental to zinc electrowinning. Preliminary tests carried out at room temperature indicated that the addition of 10 g/L zinc dust, with a retention time of 15 minutes, was sufficient to reduce the concentration of the metallic impurities to acceptable levels.

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Zinc was then extracted from the cemented solution in a second solvent extraction operation using 30% v/v D_2EHPA in kerosene, and the zinc was stripped with 40 g/L Zn + 180 g/L H_2SO_4 to produce a sulphate electrolyte for zinc electrowinning. Zinc electrowinning tests were run for 6 h at 430 A/m^2 and 35°C to determine the current efficiency and deposit morphology/orientation. The above purification procedure yielded good quality zinc electrodeposits at high current efficiency. Furthermore, the effects of gelatin, licorice and Sb on the current efficiency and the deposit orientation/morphology were also determined.

Keywords: Zincex process, zinc dust purification, chloride solution, solvent extraction, zinc electrowinning, deposit morphology/orientation.

BACKGROUND

Over the past fifteen years, CANMET has developed expertise on impurity effects in zinc electrowinning from conventional zinc sulphate electrolyte that has gained world-wide recognition. Part of CANMET's current in-house research on zinc sulphate electrolysis includes a study of the effects of the so-called inert inorganic species; i.e., $MnSO_4$, $MgSO_4$, Na_2SO_4 and K_2SO_4 that are normally present in the industrial solutions as well as a study of the effects of certain organic substances; e.g., D_2EHPA commonly used in zinc solvent extraction (SX) processes.

During this same period, CANMET also pioneered the development of a zinc electrowinning process that produces smooth, compact, dendrite-free deposits from aqueous zinc chloride electrolyte. Closely associated with the zinc chloride electrolysis was CANMET's successful application of the conventional zinc dust cementation technique to the purification of zinc chloride process solutions to remove detrimental impurities prior to zinc electrowinning.

In recent years, Technicas Reunidas developed a two-stage SX process, the Zincex process, that produces an acid-sulphate zinc electrolyte from a zinc chloride leach solution. This process is currently being used by Quimigal in Lisbon to produce cathode zinc from pyrite cinders. Unlike conventional solutions, the SX-produced zinc sulphate electrolyte contains only very low concentrations of $MnSO_4$ and $MgSO_4$; however, it can contain

entrained organics such as D_2EHPA carried over from the SX stage. Further, the second SX stage, which converts the zinc chloro-complex to zinc sulphate, does not eliminate totally the impurities detrimental to zinc electrowinning. Since the zinc chloride solution is nearly neutral it is possible that the majority of metallic impurities could be removed by adding zinc dust prior to the second solvent extraction step.

The incorporation of Quimigal's Zincex process solutions into CANMET's in-house zinc electrolysis research program, therefore, provided an invaluable opportunity for CANMET to extend its work on synthetic electrolytes to actual plant solutions that had similar characteristics and to apply CANMET's zinc dust purification expertise to commercial chloride process solutions.

INTRODUCTION

In many parts of the world, sulphuric acid is produced by roasting pyrite ores. The SO_2 produced in the roasters is converted into sulphuric acid using conventional technology, and the resulting cinders are often processed to recover the minor amounts of Cu, Zn, Ag, Pb, etc. which were present in the original pyrite ore. Quimigal operates such a pyrite roasting facility at Barreiro, near Lisbon, Portugal. At this facility, the cinders from the pyrite roasting operation are mixed with salt and are then re-roasted in multi-hearth furnaces to convert the base metals into their respective chlorides. The cinders from the chloridizing roast are water leached to give a solution containing significant concentrations of Cu, Ag, Zn, Pb, Cd and Fe, all of which are present in a mixed chloride-sulphate medium. Copper and silver are recovered by cementation on scrap iron, and the resulting solution is then treated by the Zincex process (1) to recover zinc, Figure 1. Initially, $ZnCl_2$ is extracted from the mixed chloride-sulphate solution with Amberlite LA-2; the strip liquor is nearly-neutral (<1 g/L HCl) impure zinc chloride solution containing ≈20 g/L Zn. Zinc is then extracted using D_2EHPA, and the zinc is stripped into a $ZnSO_4$-H_2SO_4 electrolyte. Following activated carbon treatment of the solution, zinc is recovered by conventional sulphate-based electrolysis, and the spent electrolyte is recycled to strip more zinc from the loaded D_2EHPA.

A typical 24-h Quimigal Zincex zinc deposit was examined at CANMET by scanning electron microscopy (SEM) to determine the surface morphology and by X-ray diffraction analysis (XRD) to obtain the preferred orientation relative to the ASTM standard for zinc powder. The secondary electron (SE) micrograph given in Figure 2 shows the surface to consist of numerous holes or pits which seem to extend all the way to the original aluminum cathode. These holes likely reflect H_2 gassing accompanied by re-solution of the zinc during electrolysis. Aside from the holes, the surface of the metal is flat and smooth. The preferred orientation of this deposit was [002]; i.e., basal, as opposed to the intermediate orientation, [112][114][102] usually observed for zinc deposits obtained from conventional zinc plants. The [002] preferred deposit orientation and the numerous holes in the zinc deposit suggest that the electrolyte contains concentrations of metallic impurities and/or residual organics detrimental to zinc electrowinning.

Some preliminary electrowinning tests were done at CANMET using as-received Quimigal activated carbon-treated zinc sulphate electrolyte. The effects of Mn^{2+} and Sb + glue additions on the current efficiency and deposit morphology/orientation of 1-h zinc deposits electrowon at 430 A/m^2 and 35°C were determined. Manganese additions did not change significantly the current efficiency (≈86%) obtained for the 1-h zinc deposits. The preferred orientation of all the deposits was [002] similar to that found for the commercial Quimigal deposit mentioned above.

The deposit morphology is depicted in a series of SE micrographs, Figure 3. The surface of the addition-free deposit, Figure 3(a), contains many holes (sites of H_2 evolution) and is very similar to the surface of the commercial deposit; cf., Figure 2. This deposit, Figure 3(a), does not reflect the distinctive zinc structure in that there are no clearly defined zinc platelets. The addition of Mn^{2+} reduces the number of surface holes but otherwise the deposit morphology remains the same, Figure 3(b). This morphology coupled with the [002] orientation suggests the presence of significant concentrations of metallic impurities, even in the treated electrolyte. Subsequent analysis of this electrolyte for several commonly-encountered impurities was carried out, and the results for the Quimigal electrolyte are compared with those of typical Cominco electrolyte in Table 1. Compared to the Cominco electrolyte, the common impurities are at least an order of magnitude higher in the Quimigal solution.

The addition of Sb + glue to the Quimigal electrolyte did not improve the current efficiency (probably because of the high level of impurities, Table 1), but did change the preferred orientation and deposit morphology. The deposit orientation obtained for the addition of 0.04 mg/L Sb + 15 mg/L glue was [112][110][101], and this orientation is typical of a good zinc deposit. The SE micrographs, Figure 4, show that the deposit is smooth, flat and contains no holes; it consists of zinc platelets oriented at intermediate angles to the Al cathode. This result

suggests that better control of the Sb to glue ratio may have a beneficial effect on zinc deposition from Zincex process electrolyte.

In recent years, the Quimigal plant has experienced a substantial and continuing decrease in the zinc electrowinning current efficiency, and one possible cause of the decrease in the current efficiency is the build-up of low concentrations of detrimental metallic impurities in the circulating electrolyte. It was felt that a zinc dust cementation process inserted between the first and second solvent extraction operations might be an effective means of controlling the impurity build-up in the circulating electrolyte. It should be noted that cementation of the $ZnSO_4$ solution produced in the second (D_2EHPA) cementation stage is not possible because of the high acidity of this solution. Accordingly, solutions were obtained from the various parts of the Quimigal SX-EW circuit, as marked on Figure 1, and preliminary tests were done to determine the effectiveness of zinc dust cementation on the impurity content of the zinc electrolyte and on the subsequent zinc electrolysis operation. The results of this preliminary investigation are presented below.

EXPERIMENTAL

1. Cementation

Unless otherwise stated, the zinc dust cementation tests were carried out in a vessel containing 300 mL of Quimigal Solution #1 (see Table 2) which is the impure $ZnCl_2$ solution from the first-stage solvent extraction operation. The cementation vessel was fitted with a cover to hold and position a thermometer and stirrer. The cover also contained an inlet for N_2 gas sparging and a sampling port from which solution samples were withdrawn at timed intervals for analysis by atomic absorption spectrophotometry. The tests were generally run for 15 minutes at room temperature.

2. Solvent Extraction

Following zinc dust cementation, the solutions were filtered and then subjected to solvent extraction using 30% (v/v) D_2EHPA in kerosene. The extraction of zinc was done using an aqueous volume/organic volume (A/O) ratio of 1.5/1. Following extraction, the organic phase was scrubbed with a solution containing 1 g/L H_2SO_4 using an A/O ratio = 1/10 at room temperature. After scrubbing, the loaded organic was contacted with synthetic zinc electrolyte containing 40 g/L Zn + 180 g/L H_2SO_4. The A/O ratio was 1/1.5 and this yielded a final electrolyte containing about 60 g/L Zn and 140 g/L H_2SO_4. This electrolyte was passed through a column containing activated carbon to remove any entrained or dissolved organics.

3. Electrowinning

The electrowinning cell consisted of a 1-L beaker fitted with a Lucite cover to hold and space the electrodes. The cathode was a piece of commercial aluminum having an exposed surface area of 10.2 cm^2. The cathode was centered between two Pt anodes; Pt anodes were chosen to avoid lead effects from the corrosion of the Pb-Ag anodes used in commercial practice. The electrowinning tests were run for 6 h at a current density of 430 A/m^2 and 35°C. Antimony, gelatin and licorice were added to the electrolyte as aliquots from their respective stock solutions as required.

Following the electrolysis period, the cathode was removed from the cell and the deposited zinc was thoroughly rinsed with water, stripped from the Al, dried and weighed. The current efficiency was determined from the weight of the zinc and the current passed. Sections of the deposits were examined by X-ray diffraction (XRD) to determine their preferred orientation relative to the ASTM standard for zinc powder and by scanning electron microscopy (SEM) to determine their surface morphology.

RESULTS AND DISCUSSION

1. Quimigal Solution Analyses

Four solutions as indicated in Figure 1 were received from Quimigal and were labelled as follows:

Solution #1. Solution obtained after the first solvent extraction stage with Amberlite LA-2 - a chloride solution.
Solution #2. Solution obtained after the second solvent extraction stage with D_2EHPA but prior to treatment with activated carbon - a sulphate solution.
Solution #3. Solution obtained after the second solvent extraction stage following activated carbon treatment - a sulphate solution.
Solution #4. Cell feed electrolyte; presumably the second solvent extraction solution after activated carbon treatment and dilution with spent electrolyte.

These four solutions were analyzed at CANMET and the results are summarized in Table 2. Although the concentrations of impurities such as Cd, Cu and Fe are reduced considerably after the second solvent extraction step, the levels of these impurities in the cell feed are still too high to yield high current efficiencies during zinc electrolysis. Furthermore, impurities such as Ni, Pb and Sn, that are also detrimental to zinc electrowinning, become more concentrated in the electrolyte after the second solvent extraction step.

2. Zinc Dust Cementation

Zinc dust cementation is used in conventional sulphate-based zinc plants to reduce the concentration of detrimental impurities contained in the neutral leach solution to levels acceptable for zinc electrowinning. In the Zincex process, it is not practical to treat the second-stage (D_2EHPA) solvent extraction strip solution or the cell feed with zinc dust because of their high acid concentrations. The first-stage (Amberlite LA-2) solvent extraction strip liquor, however, contains less than 1 g/L free HCl, Table 2; thus it should be amenable to treatment with zinc dust to reduce the concentrations of the impurity elements.

The as-received Quimigal Solution #1, Table 2, was subjected to zinc dust cementation according to the conditions outlined in the Experimental Section. A preliminary test was done to assess the feasibility of Zn dust cementation using 1-L of solution to which 8 g of fine Zn dust was added with stirring at room temperature. The test was run for 1-h, but a sample was taken after 15 min and was analyzed for Cu, Cd and Pb using atomic absorption spectrophotometry. The results, summarized in Table 3, indicate that the Cu, Cd and Pb impurities were reduced to acceptable levels after 15 min reaction time. A more complete analysis of the final filtered solution; i.e., after 1-h cementation, indicated that the concentrations of As, Ni and Sn were also reduced significantly by the addition of the Zn dust. The Fe concentration decreased from 35 to 0.03 mg/L. This

occurred because the pH increased to ≈5 after the first 5 min of reaction and caused the iron to precipitate. Presumably the <1 g/L free acid was neutralized by the Zn dust during the initial stage of cementation thereby causing the pH to rise. After iron precipitation, the cementation of the metal impurities continues and the final solution filters readily.

A series of tests was run to determine the amount of zinc dust required to reduce the Cu, Cd and Pb concentrations to acceptable levels for zinc electrowinning in a 15 min period under well defined experimental conditions. A volume of 300 mL of Solution #1 was used to which 0.3, 0.5, 0.75, 1.0, 2.0, 3.0 and 4.0 g of Zn dust were added. The solution was stirred and periodic samples were taken over a 15 min period for the analysis of Cu, Cd and Pb. The results, in the form of metal cemented vs time plots, are presented in Figures 5 to 7. The following conclusions can be drawn from these results:

1) The initial rate of Cu, Cd and Pb cementation increases with increasing zinc dust concentration.
2) There is only a small increase in the initial cementation rate when the zinc dust is increased from 3 to 4 g (i.e., from 10 to 13.3 g/L).
3) There is a substantial increase in the initial cementation rates for Cu and Cd when the zinc dust is increased from 2 to 3 g (i.e., from 6.7 to 10 g/L).

4) The largest increase in the initial Pb cementation rate occurs when the zinc dust is increased from 0.5 to 0.75 g (i.e., from 1.7 to 2.5 g/L).

5) The addition of 10 g/L Zn dust removes virtually all the Cu and Pb and most of the Cd after 3-4 minutes. It should be noted, however, that the Cd is never completely removed from solution and at low levels of Zn dust, it has a tendency to redissolve with increasing retention time.

6) It appears that for a 15 min retention time and a single stage cementation reactor, 10 g/L Zn dust is necessary to ensure that the Cu, Cd and Pb impurities are reduced to sufficiently low levels to allow zinc to be electrowon at high current efficiency.

As mentioned earlier, the pH increases and most of the iron contained in the solution precipitates during the initial minutes of Zn dust cementation. The slurry filters readily and the final pH ≈5 is ideal for the second solvent extraction stage.

Although these results indicate that the addition of 10 g/L zinc dust gave good cementation results with a 15 min retention time, only ≈1.5 g/L zinc dust was actually consumed over a 1-h period, Table 3. Much of the zinc dust was consumed by reaction with the 0.7 g/L HCl concentration of the solution, and the use of high purity industrial lime in a preneutralization circuit would significantly reduce zinc dust consumption. In any event, 10 g/L zinc dust addition represents a considerable excess of

zinc dust over that consumed by the cementation reaction. It is possible that the zinc dust consumption could be reduced by using a 2- or 3-stage cementation process with both recycle and lower zinc dust additions. The use of longer cementation periods would significantly reduce the amount of zinc dust required, but could result in some re-solution of cadmium. It is also likely that the cement product could be dissolved in H_2SO_4, which is produced on site, and then recycled to the first-stage solvent extraction operation to recover the zinc used in cementation.

3. Solvent Extraction

The filtered solution from zinc dust cementation was subjected to solvent extraction using D_2EHPA in kerosene according to the procedure outlined in the Experimental Section. During the second-stage solvent extraction, the pH of the aqueous phase decreased as Zn^{2+} ions were replaced with H^+ ions. When the pH decreased to ≈1, the extraction stopped (≈5 min). At this point, the pH was adjusted to 4.5-5 by the addition of concentrated NH_4OH. This procedure was repeated several times during the extraction stage to ensure maximum Zn loadings of the organic phase. It should also be noted that a similar technique, using lime additions to the mixer-settlers, is employed at Quimigal.

Following the scrubbing stage, the organic phase was stripped of its zinc content by contacting it with a solution containing 40 g/L Zn + 180 g/L H_2SO_4. This produced a final

electrolyte containing approximately 60 g/L Zn + 140 g/L H_2SO_4. This electrolyte was passed through a column containing activated carbon to remove any entrained or dissolved organics. Known volumes of this solution were then subjected to electrolysis under the conditions outlined in the Experimental Section.

4. Zinc Electrowinning

Eight electrowinning tests were run for 6 h at a current density of 430 A/m^2 and 35°C. At Quimigal, both gelatin and licorice are added to the electrolyte to control the deposit growth and to suppress acid mist, respectively. Thus a few of the tests were done with these reagents present in the electrolyte. As well, a few tests were done to evaluate the effect of antimony additions. The current efficiency and preferred deposit orientation results obtained from these tests are presented in Table 4.

The current efficiency for the addition-free deposit was 96.2% and the preferred orientation was [002], Table 4. The deposit surface was flat and relatively smooth, but contained a few isolated circular holes which are indicative of zinc re-solution, Figure 8(a). The deposit consists of poorly defined hexagonal platelets aligned at low angles to the Al cathode, Figure 8(b), resulting in the basal, [002] orientation, Table 4.

Surprisingly, the addition of 3 mg/L gelatin or 3 mg/L licorice had no effect on the current efficiency or on the deposit orientation which remained [002], Table 4. The surface

of these deposits, Figure 9(a), although similar to the addition-free deposit, contained many more circular holes. The poorly defined zinc platelets were aligned at low angles to the Al cathode, Figure 9(b), consistent with the [002] orientation given in Table 4.

Two tests were done using an electrolyte to which was added 0.01 mg/L Sb; the average current efficiency was 95.9% and the preferred deposit orientation changed from [002] to either [112][101][114] or [112][110][101]. The deposit surface consisted of numerous, large circular holes, Figure 10(a), but for this sample the zinc platelets are aligned at intermediate angles to the Al cathode, Figure 10(b), resulting in the [112][101][114] orientation, Table 4.

The combined addition of 3 mg/L gelatin + 3 mg/L licorice + 0.01 mg/L Sb to the electrolyte resulted in a current efficiency of 96.8% and a deposit having a [112][114][102][103][101] preferred orientation, Table 4. More importantly, this combination of additives eliminated the circular holes from the deposit surface and produced a relatively smooth deposit, Figure 11(a). The deposit consisted of sharply defined hexagonal platelets aligned at intermediate angles to the Al cathode, Figure 11(b), that resulted in the [112][114][102][103][101] preferred deposit orientation, Table 4. Increasing the Sb concentration to 0.02 mg/L in the presence of 3 mg/L gelatin + 3 mg/L licorice decreased the current efficiency to 93.0% and resulted in a [110][112] preferred orientation, Table 4. The

zinc deposit surface, Figure 12(a), consisted of distinct rows of flat nodules giving the deposit a macroscopically striated appearance. The vertical alignment of some of the zinc platelets is clearly visible in Figure 12(b) and this resulted in the [110] component of the orientation given in Table 4.

CONCLUSIONS

Preliminary tests have shown that impurities such as Cu, Cd Pb, Ni, As, Sb and Sn can be reduced to concentrations acceptable for zinc electrowinning by the zinc dust cementation of the first-stage solvent extraction strip solution from the Zincex process. The cementation studies showed that 10 g/L zinc dust and 15 minutes retention time at room temperature reduced the concentration of the impurities to acceptable levels for efficient zinc electrowinning. During cementation, the solution pH rises to ≈5 and this is ideal for the second solvent extraction stage. During the second-stage solvent extraction operation, the solution pH decreased and it was necessary to adjust the pH to ≈5 by the periodic addition of concentrated NH_4OH. It is likely that the amount of zinc dust required to cement the undesirable metals could be reduced by operating a 2- or 3- stage cementation unit or by extending the cementation time, and these possibilities should be examined in future studies. Also, the feasibility of recovering zinc dust not consumed during cementation by dissolution of the cement product in H_2SO_4 should be determined.

The volume of final electrolyte produced was sufficient for only eight electrowinning tests and these tests could be run in a batch mode for only 6 h because of zinc depletion. The current efficiency for all the tests was ≈96% and the predominant deposit orientation was [002] even in the presence of gelatin and licorice. Surprisingly, the addition of Sb changed the orientation to [112][101][114] or [112][110][101]. The deposit surface was characterized by numerous circular holes (H_2 evolution?) which are indicative of zinc re-solution. The combination of addition agents; viz., 3 mg/L gelatin + 3 mg/L licorice + 0.01 mg/L Sb, eliminated the surface holes and produced a deposit having a [112][114][102][103][101] preferred orientation. It appears that better control of the antimony to glue ratio of Quimigal electrolyte would enhance the energy efficiency of zinc electrowinning and also would improve the product quality.

It must be emphasized that these results are only preliminary and should be confirmed on a continuous scale over a 24-h electrolysis period using conditioned Pb-Ag anodes. Any additional testwork should focus on reducing the amount of zinc dust required in the cementation operation and on maintaining a balanced antimony to glue ratio in the electrolyte. The effect of adding 1-2 g/L Mn^{2+} to the electrolyte to minimize anode corrosion or the use of $SrCO_3$ to control dissolved Pb should also be investigated.

ACKNOWLEDGEMENTS

Thanks are due to R. Molnar for providing advice on the solvent extraction procedures and to P. Carriere for doing the X-ray diffraction measurements.

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Table 1. Analyses of Quimigal and Cominco Zinc Electrolytes

Electrolyte	Cd	Co	Cu	Mn (mg/L)	Ni	Pb	Sb
Quimigal	0.2	1.1	0.5	39	1.3	1.5	0.07-0.03
Cominco	0.2	0.3	0.1	1600	0.1	0.2	0.02

Table 2. Analyses of the As-received Quimigal Solutions

Solution (#)	Zn (g/L)	Free Acid (g/L)	Cl (g/L)	As	Cd	Co	Cu	Fe	Ni	Mn	Pb	Sb	Sn
							(mg/L)						
1	16.7	0.7	19.7	0.5	31	0.4	8	35	0.1	1	5	0.004	0.1
2	69.2	84.5	0.3	<0.1	0.3	0.4	0.8	17	0.3	34	8	0.002	1
3	69.6	82.1	0.3	<0.1	0.3	0.4	0.8	17	0.4	34	8	0.001	1
4	44.5	123	0.2	0.3	0.3	0.5	0.5	17	0.4	56	7	<0.001	2

Table 3. Analyses of the First-Stage Solvent Extraction Strip Solution Before and After Zinc Dust Cementation

Solution	Zn (g/L)	Cl (g/L)	Free Acid (g/L)	As	Cd	Co	Cu	Fe	Mn	Ni	Pb	Sb	Sn
							(mg/L)						
Feed to Cementation	16.7	19.7	0.7	0.5	31	0.4	8	35	1	0.1	5	0.004	0.1
After 15 min	-	-	-	-	0.5	-	0.2	-	-	-	<0.1	-	-
Final Solution	18.1	-	-	<0.1	0.3	0.3	0.1	0.03	-	0.03	<0.1	-	<0.1

Table 4. Current Efficiency and Orientation Data for 6-h Zn Deposits Electrowon at 430 A/m^2 and 35°C from the Second-Stage Solvent Extraction Strip Electrolyte

Gelatin (mg/L)	Licorice (mg/L)	Sb (mg/L)	CE (%)	ORIENTATION[1]
0	0	0	96.2	002
3	0	0	96.0	002
0	3	0	96.6	002
0	0	0.01	94.8	112, 101, 114
0	0	0.01	96.9	112, 110, 101
0	3	0.01	96.7	112, 101
3	3	0.01	96.8	112, 114, 102, 103, 101
3	3	0.02	93.0	110, 112

[1]Relative to ASTM standard for zinc powder

FIGURE CAPTIONS

Fig. 1 - Simpified flowsheet for the Zincex process showing the solution sampling points.

Fig. 2 - A general view of the surface of a typical 24-h Quimigal zinc deposit showing the presence of numerous pits or holes.

Fig. 3 - SE micrographs showing the morphology of 1-h zinc deposits electrowon at 430 A/m^2 and 35°C from Quimigal electrolyte in the presence and absence of Mn^{2+}.

Fig. 4 - SE micrographs showing the morphology of a 1-h zinc deposit electrowon at 430 A/m^2 and 35°C from Quimigal electrolyte containing 15 mg/L glue + 0.04 mg/L Sb.

Fig. 5 - Plots of cadmium cemented vs time for various amounts of zinc dust added to Quimigal Solution #1.

Fig. 6 - Plots of copper cemented vs time for various amounts of zinc dust added to Quimigal Solution #1.

Fig. 7 - Plots of lead cemented vs time for various amounts of zinc dust added to Quimigal Solution #1.

Fig. 8 - SE micrographs showing the morphology of a 6-h zinc deposit electrowon at 430 A/m^2 and 35°C from a solvent extraction strip solution produced following zinc dust cementation of Quimigal Solution #1.

Fig. 9 - SE micrographs showing the effect of 3 mg/L licorice on the morphology of a 6-h zinc deposit electrowon at 430 A/m^2 and 35°C from a solvent extraction strip solution produced following zinc dust cementation of Quimigal Solution #1.

Fig. 10 - SE micrographs showing the effect of 0.01 mg/L Sb on the morphology of a 6-h zinc deposit electrowon at 430 A/m^2 and 35°C from a solvent extraction strip solution produced following zinc dust cementation of Quimigal Solution #1.

Fig. 11 - SE micrographs showing the effect of 3 mg/L gelatin + 3 mg/L licorice + 0.01 mg/L Sb on the morphology of a 6-h zinc deposit electrowon at 430 A/m^2 and 35°C from a solvent extraction strip solution produced following zinc dust cementation of Quimigal Solution #1.

Fig. 12 - SE micrographs showing the effect of 3 mg/L gelatin + 3 mg/L licorice + 0.02 mg/L Sb on the morphology of a 6-h zinc deposit electrowon at 430 A/m^2 and 35°C from a solvent extraction strip solution produced following zinc dust cementation of Quimigal Solution #1.

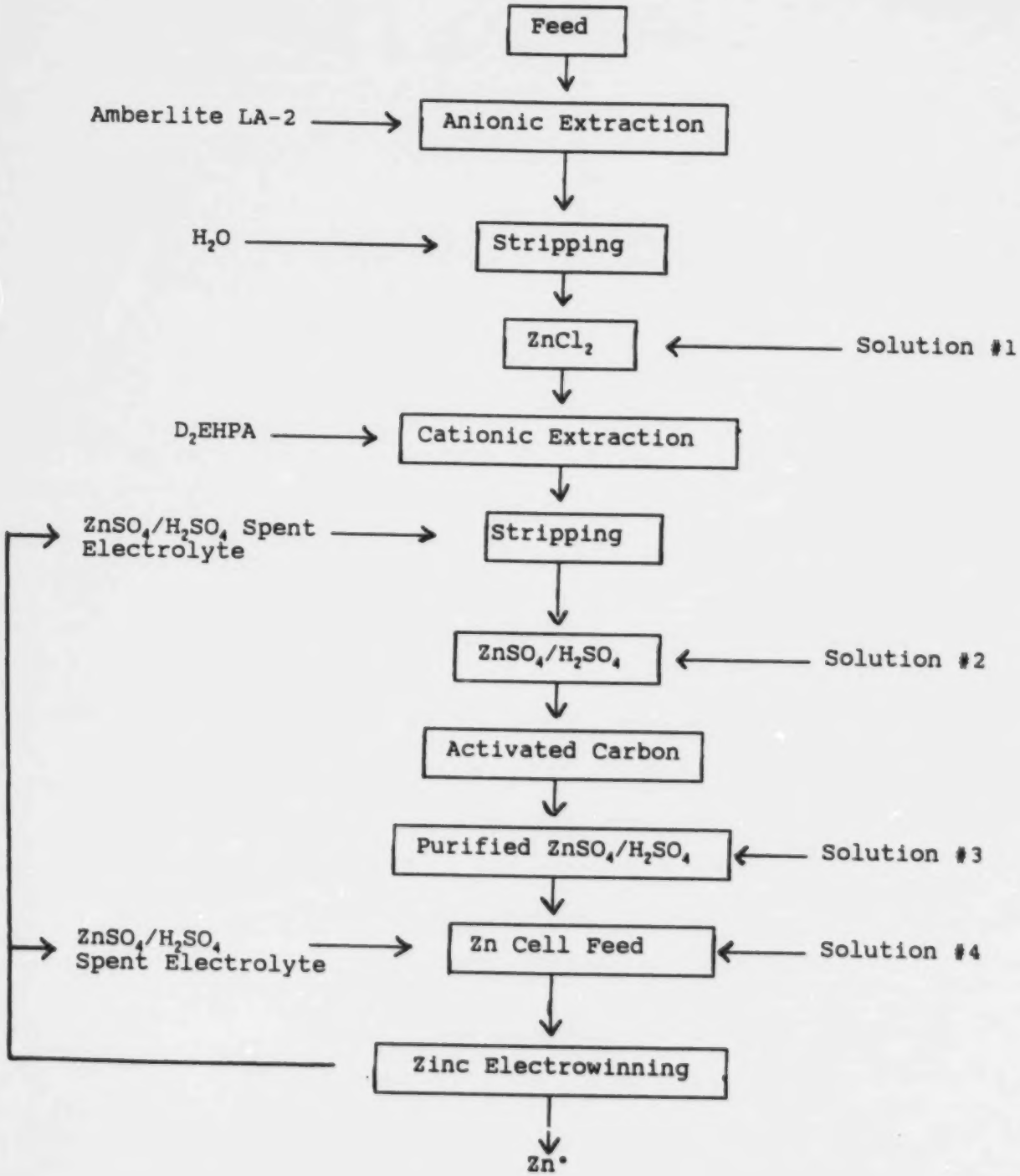


Figure 1 - Simplified flowsheet for the Zincex process showing the solution sampling points.

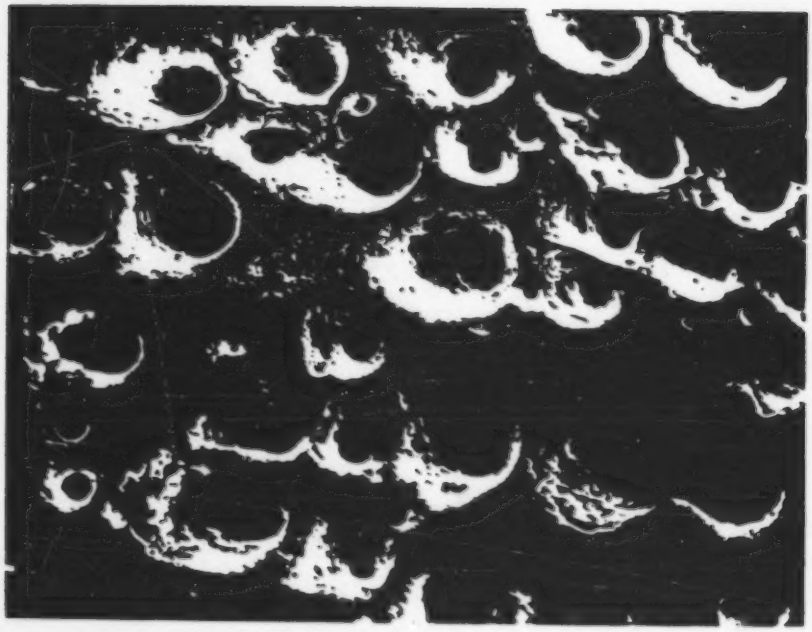
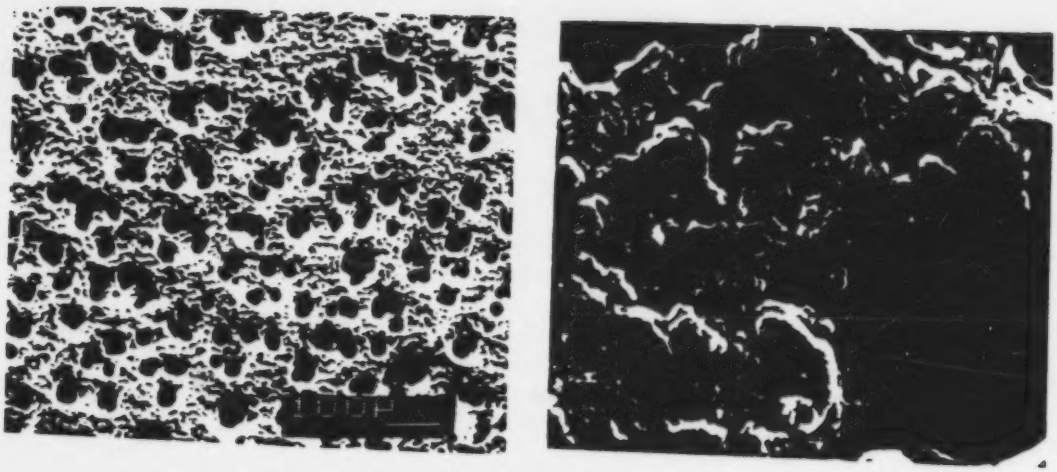
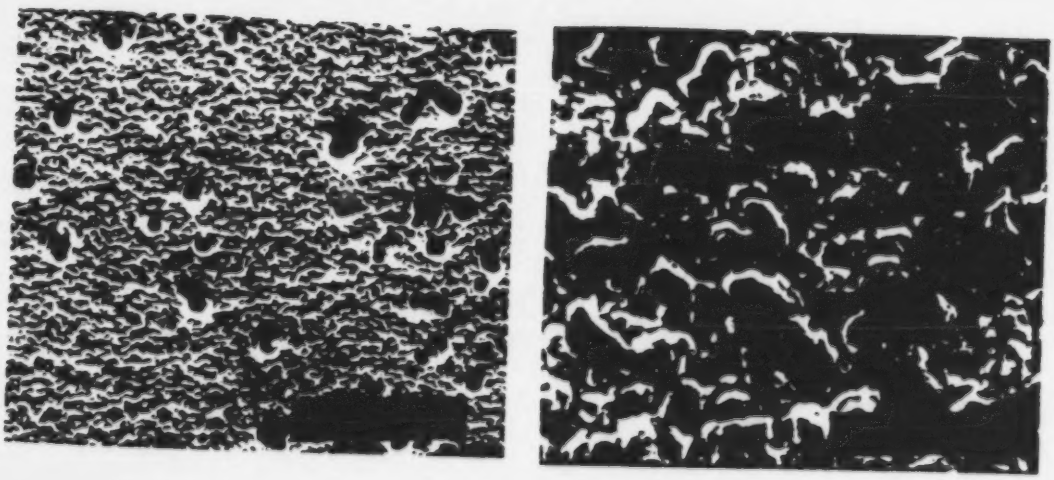


Figure 2. A general view of the surface of a typical 24-h Quimigal zinc deposit showing the presence of numerous pits or holes.



a) Quimigal electrolyte; No Mn^{2+}



b) Quimigal electrolyte; 5.0 g/L Mn^{2+}

Figure 3. SE micrographs showing the morphology of 1-h zinc deposits electrowon at 430 A/m^2 and 35°C from Quimigal electrolyte in the presence and absence of Mn^{2+}.

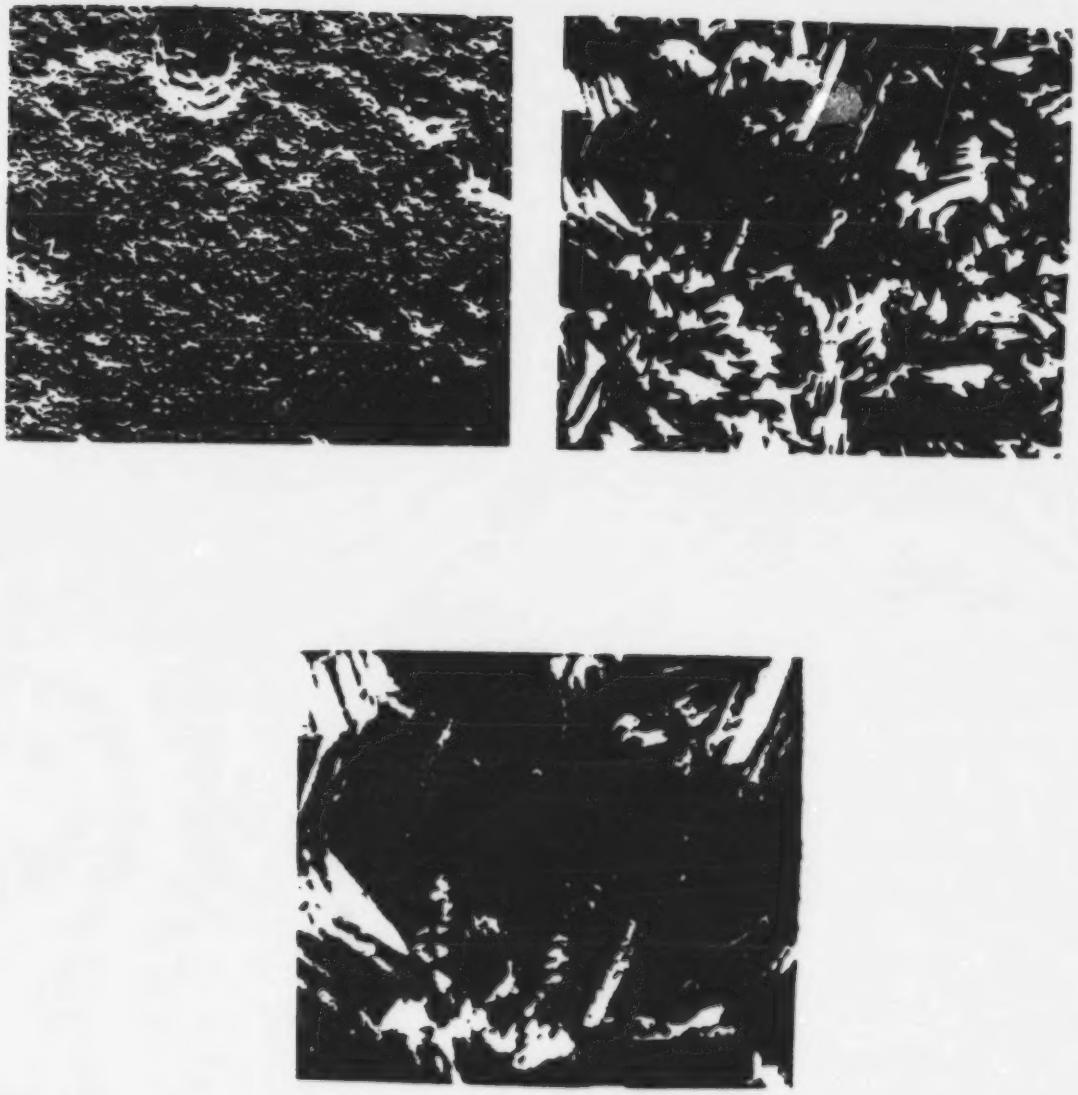


Figure 4. SE micrographs showing the morphology of a 1-h zinc deposit electrowon at 430 A/m² and 35°C from Quimigal electrolyte containing 15 mg/L glue + 0.04 mg/L Sb.

QUIMIGAL NEUTRAL SOL.

Cd CEMENTATION ON ZINC DUST

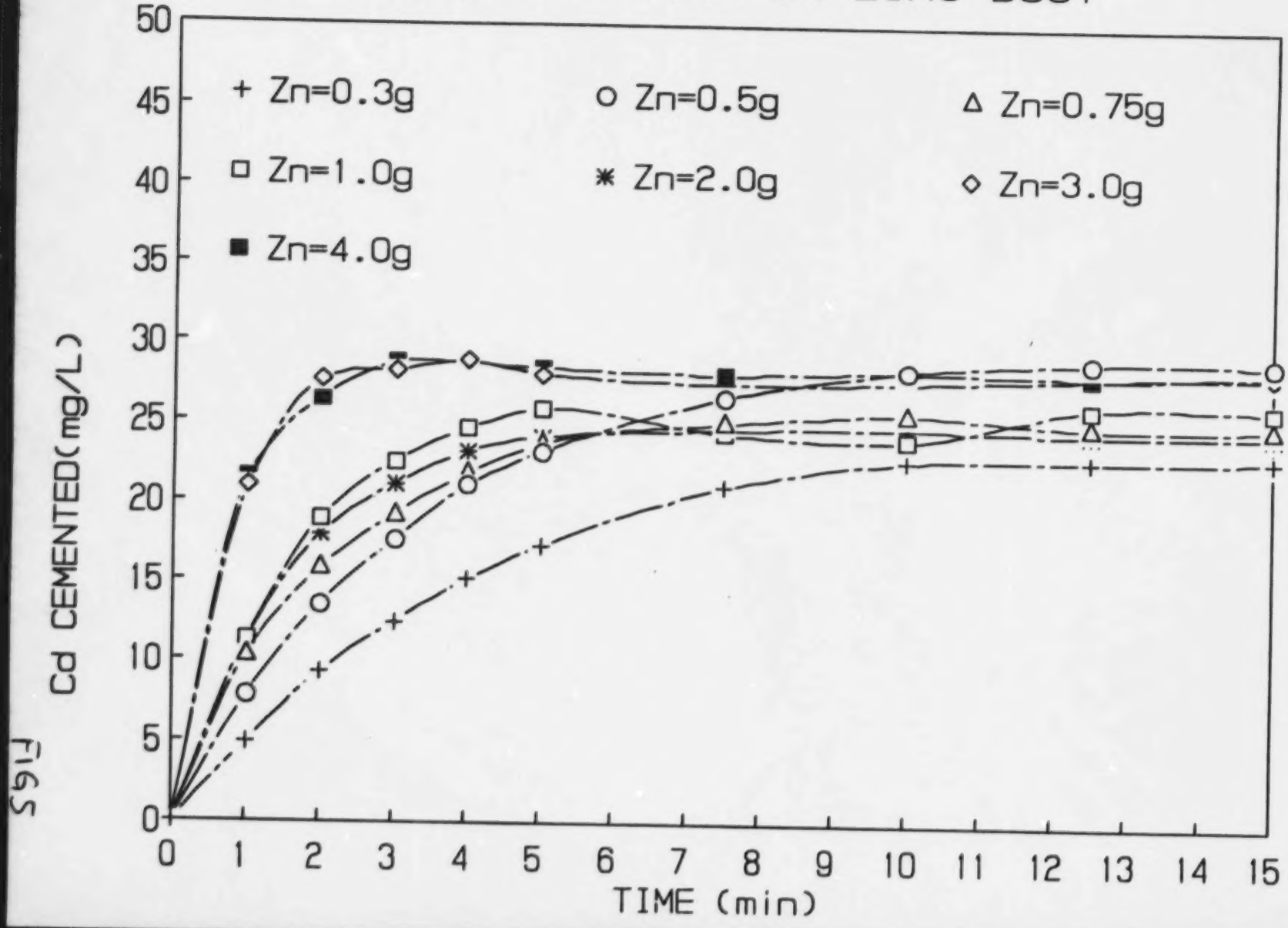


Fig 5

QUIMIGAL NEUTRAL SOLN.

Cu CEMENTATION ON ZINC DUST

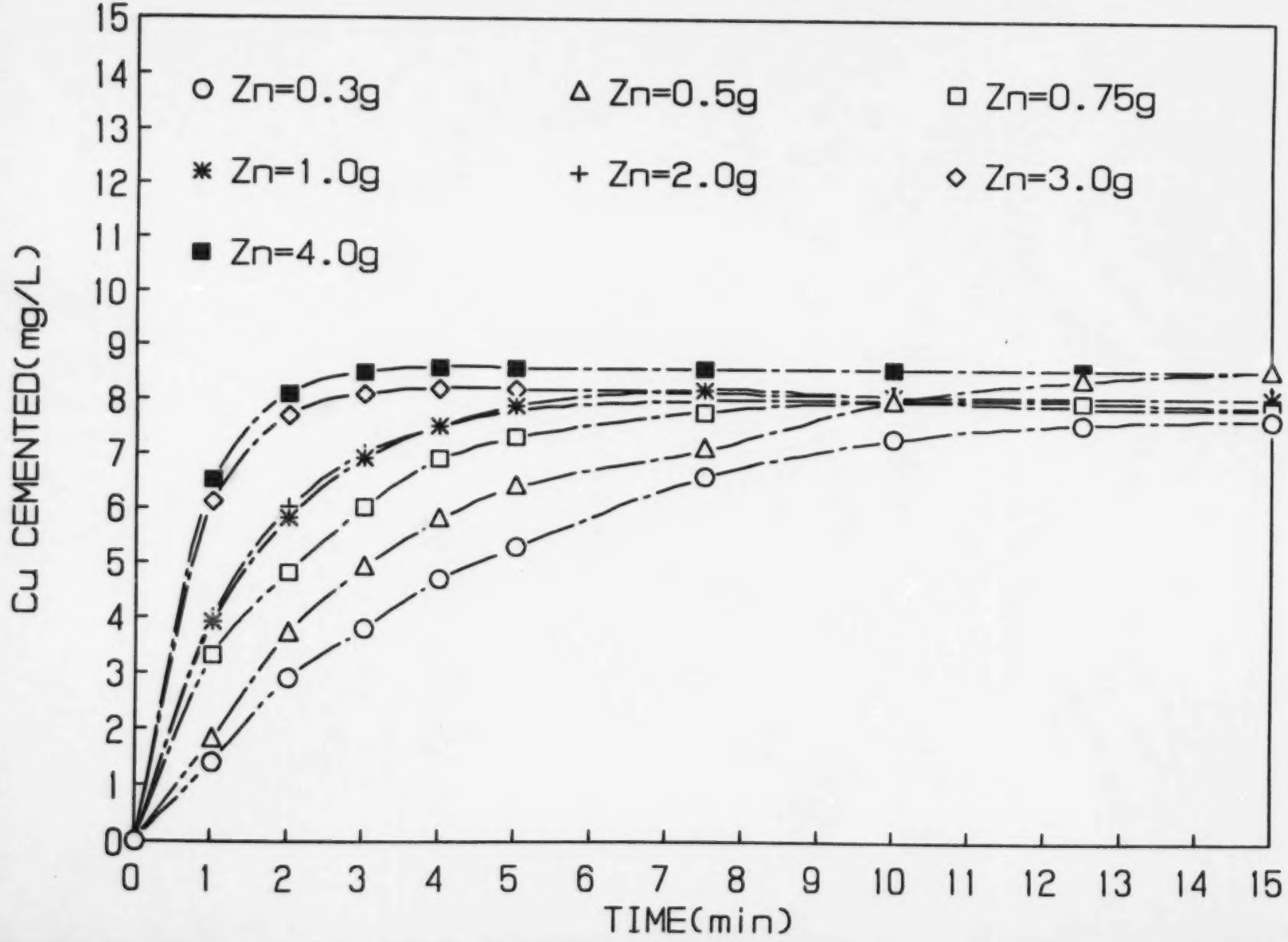
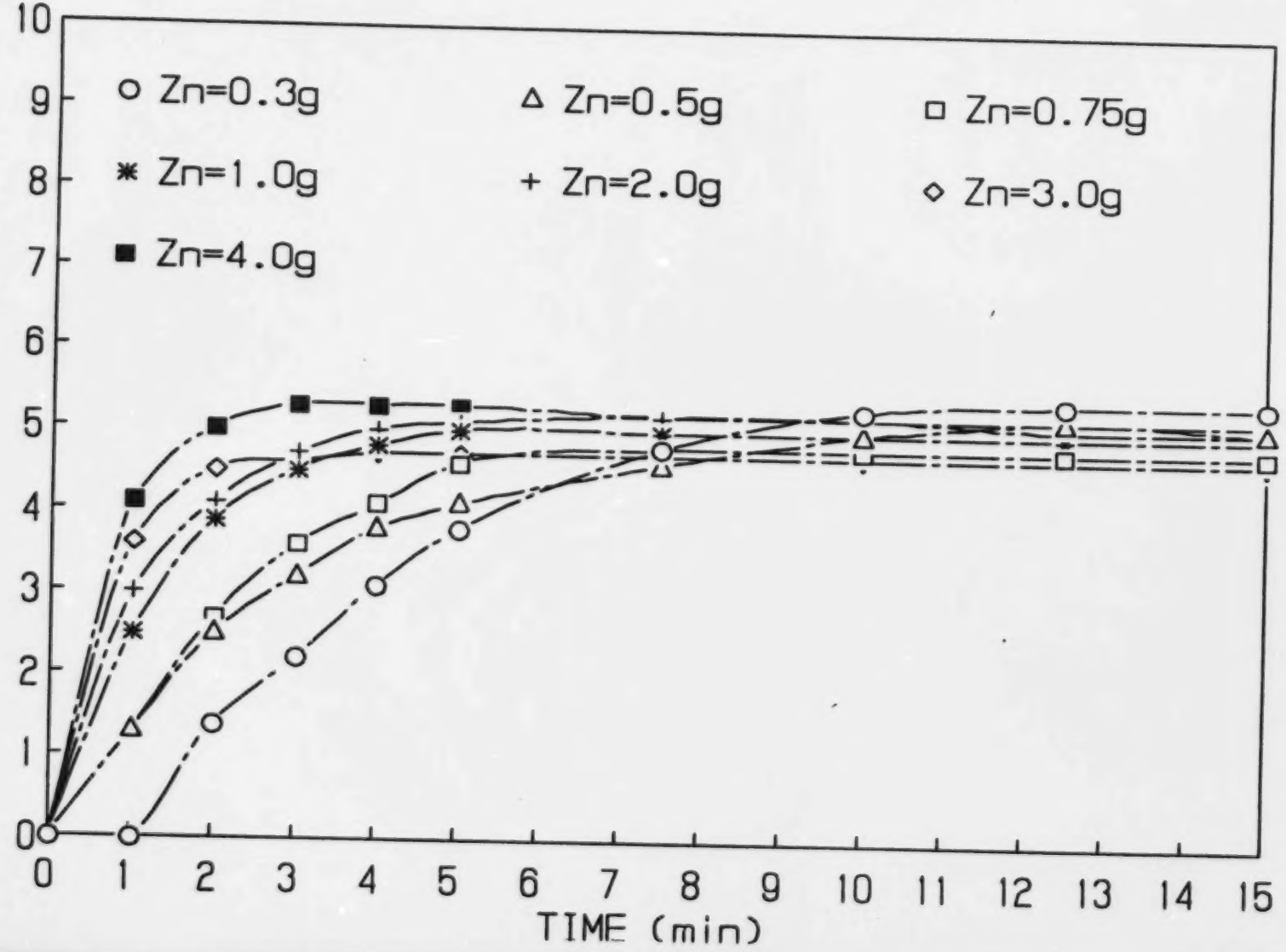


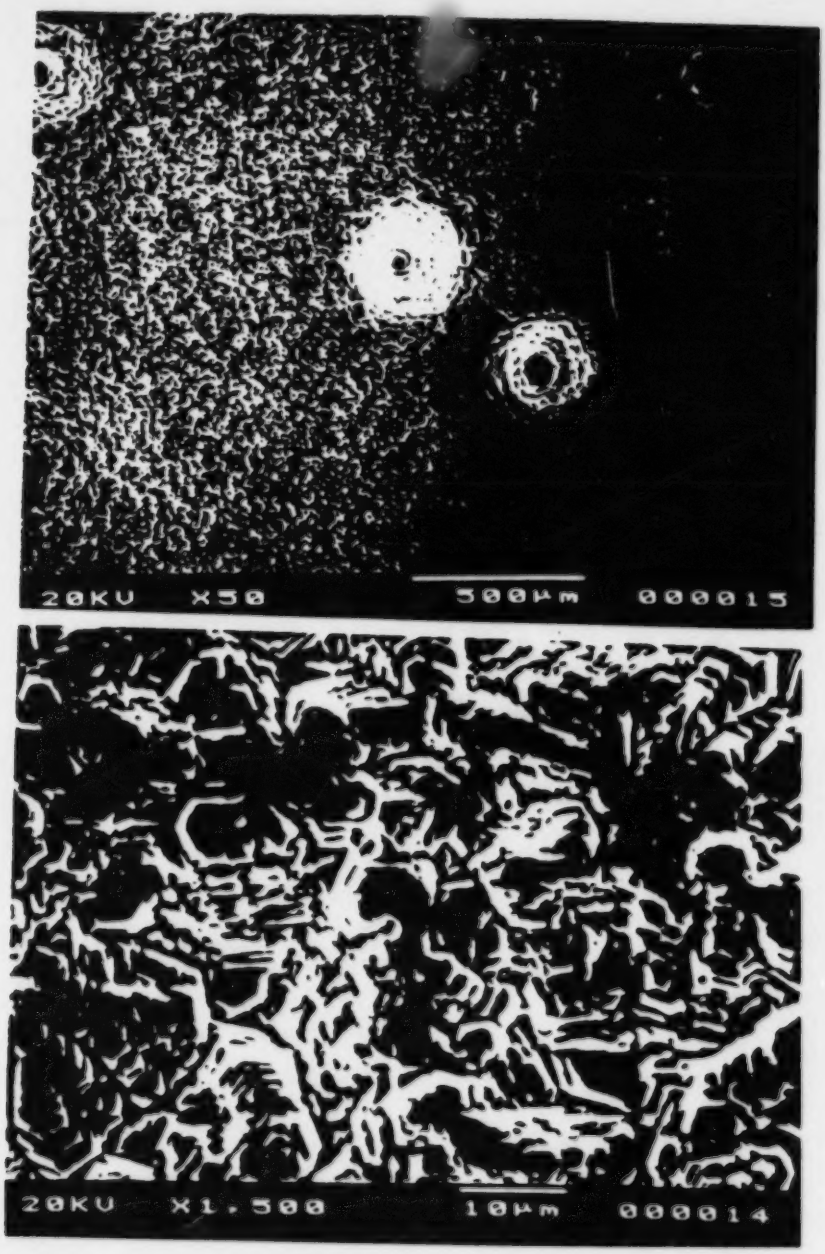
Fig 4

QUIMIGAL NEUTRAL SOLN.

PB CEMENTATION ON ZINC DUST

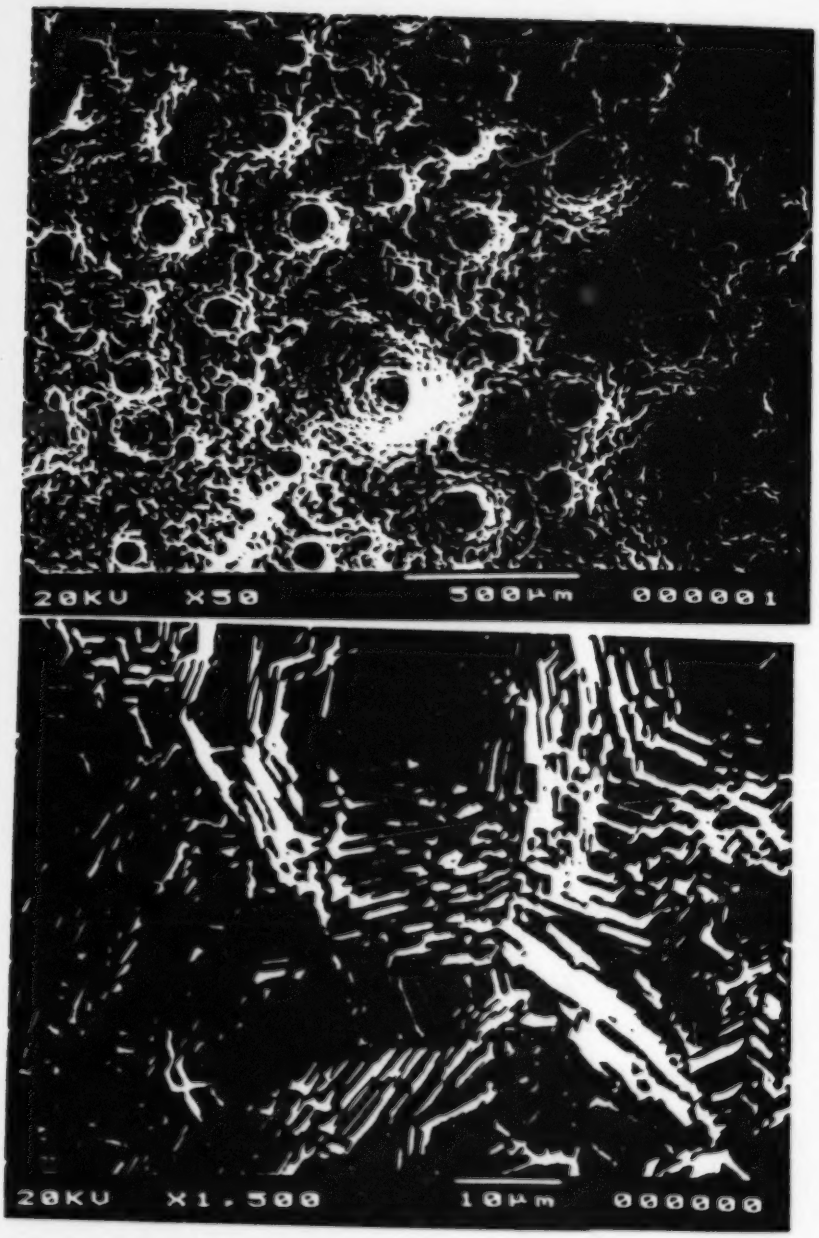


E913



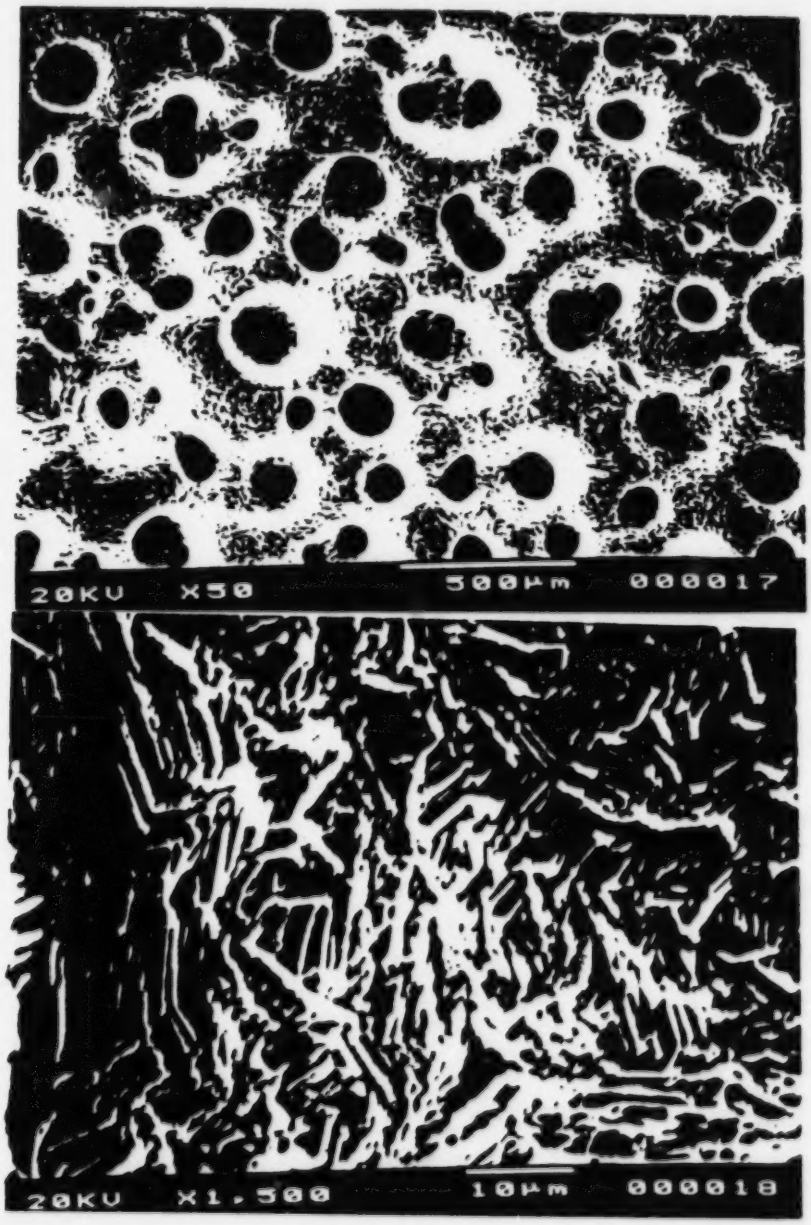
Addition-Free

Figure 8. SE micrographs showing the morphology of a 6-h zinc deposit electrowon at 430 A/m² and 35°C from a solvent extraction strip solution produced following zinc dust cementation of Quimigal Solution #1.



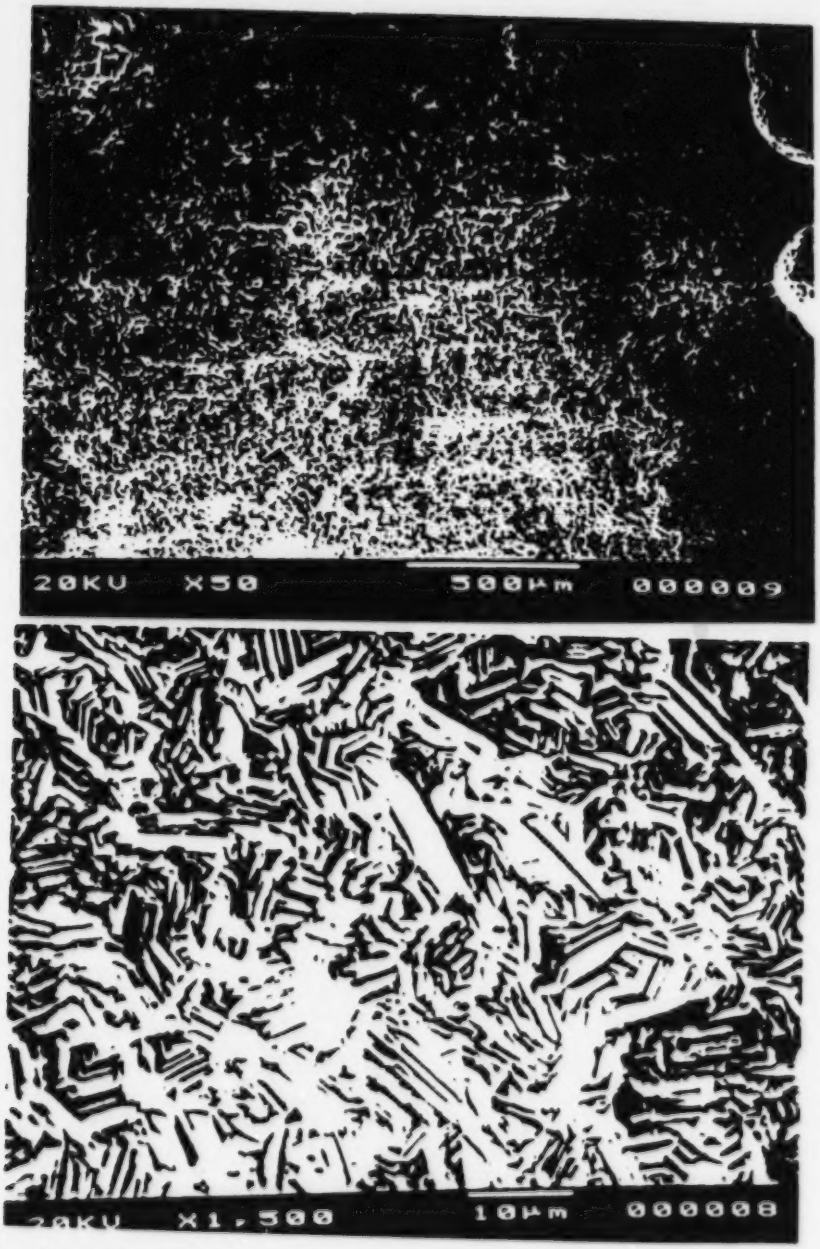
3 mg/L Licorice

Figure 9. SE micrographs showing the effect of 3 mg/L licorice on the morphology of a 6-h zinc deposit electrowon at 430 A/m^2 and 35°C from a solvent extraction strip solution produced following zinc dust cementation of Quimigal Solution #1.



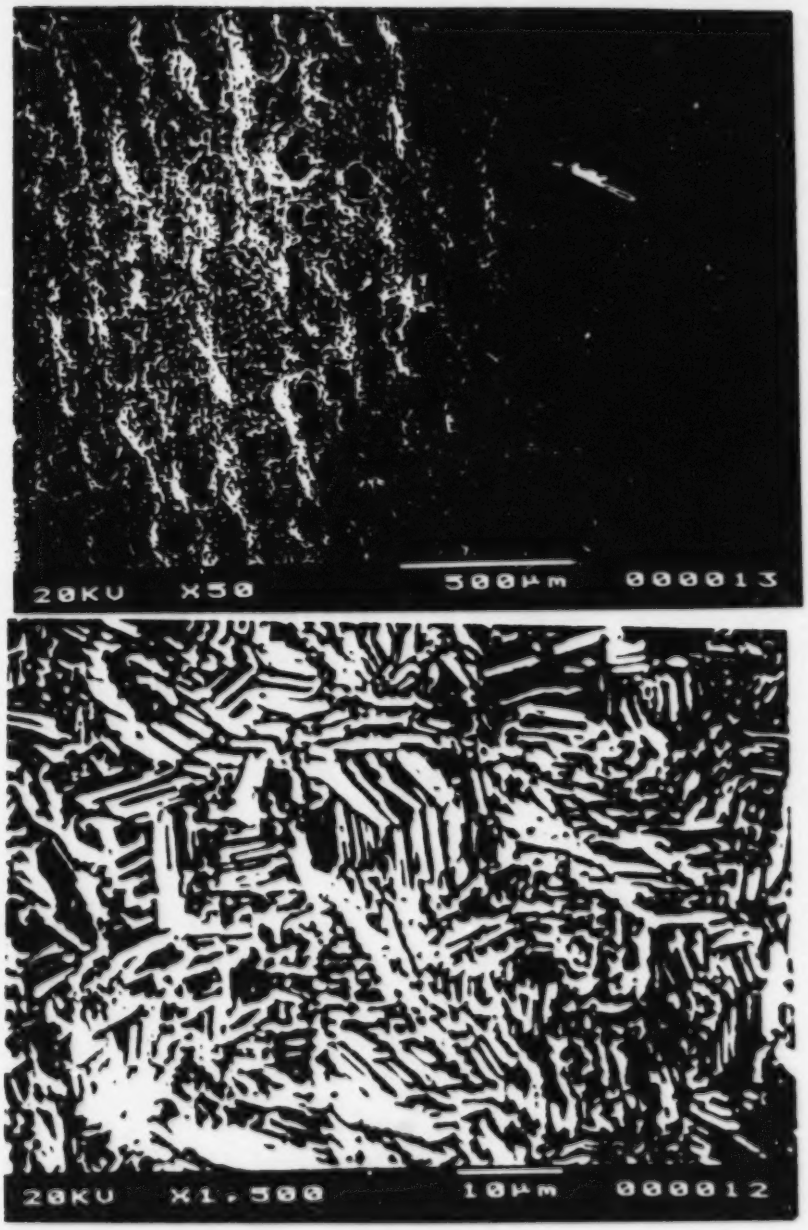
0.01 mg/L Sb

Figure 10. SE micrographs showing the effect of 0.01 mg/L Sb on the morphology of a 6-h zinc deposit electrowwon at 430 A/m^2 and 35°C from a solvent extraction strip solution produced following zinc dust cementation of Quimigal Solution #1.



3 mg/L Gelatin + 3 mg/L Licorice + 0.01 mg/L Sb

Figure 11. SE micrographs showing the effect of 3 mg/L gelatin + 3 mg/L licorice + 0.01 mg/L Sb on the morphology of a 6-h zinc deposit electrowon at 430 A/m^2 and 35°C from a solvent extraction strip solution produced following zinc dust cementation of Quimigal Solution #1.



3 mg/L Gelatin + 3 mg/L Licorice + 0.02 mg/L Sb

Figure 12. SE micrographs showing the effect of 3 mg/L gelatin + 3 mg/L licorice + 0.02 mg/L Sb on the morphology of a 6-h zinc deposit electrowon at 430 A/m^2 and 35°C from a solvent extraction strip solution produced following zinc dust cementation of Quimigal Solution #1.